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14. ABSTRACT
Psychologists have repeatedly shown that a single statistical factor—often called “general intelligence”— emerges from the correlations among people's performance on a wide variety of cognitive tasks. But no one had systematically examined whether a similar kind of “collective intelligence” exists for groups of people. In this work, we have found converging evidence of a general collective intelligence factor that explains a group's performance on a wide variety of tasks. We also found that this “c factor” is not strongly correlated with the

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Report Title

Measuring Collective Intelligence in Human-Machine Systems

ABSTRACT

Psychologists have repeatedly shown that a single statistical factor—often called "general intelligence"— emerges from the correlations among people's performance on a wide variety of cognitive tasks. But no one had systematically examined whether a similar kind of "collective intelligence" exists for groups of people. In this work, we have found converging evidence of a general collective intelligence factor that explains a group's performance on a wide variety of tasks. We also found that this "c factor" is not strongly correlated with the average or maximum individual intelligence of group members, but it is correlated with the average social perceptiveness of group members, the equality in distribution of conversational turn-taking, and the proportion of females in the group.

After the initial work with face-to-face groups, we have also developed an online test of collective intelligence that can measure a group's collective intelligence in under an hour. Among other results, we found that the average social perceptiveness of group members predicts a group's collective intelligence equally strongly in both face-to-face groups and in online groups that never see each other.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/24/2011	1.00	A. W. Woolley, C. F. Chabris, A. Pentland, N. Hashmi, T. W. Malone. Evidence for a Collective Intelligence Factor in the Performance of Human Groups, Science, (09 2010): 0. doi: 10.1126/science.1193147
12/03/2013	13.00	Ishani Aggarwal, Anita Williams Woolley. Do you see what I see? The effect of members' cognitive styles on team processes and errors in task execution, Organizational Behavior and Human Decision Processes, (09 2013): 0. doi: 10.1016/j.obhdp.2013.04.003

TOTAL: 2

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Aggarwal, I., & Woolley, A.W. (2013). Do you see what I see? The effect of members' cognitive styles on team processes and errors. Organizational Behavior and Human Decision Processes, 122(1), 92-99.

Aggarwal, I., Molinaro, M.S., & Woolley, A.W. (2013). Cognitive versatility: A new lens for understanding team diversity. Paper presented at the 8th INGRoup Conference, Atlanta, GA.

Aggarwal, I. & Woolley, A.W. (2012). Two perspectives on intellectual capital and innovation in teams. Paper presented at the International Conference on Technology Management, Indian Institute of Science, Bangalore, India.

Aggarwal, I. & Woolley, A.W. (2012). Cognitive style diversity and team creativity. Paper presented at the 7th INGRoup Conference, Chicago, IL.

Aggarwal, I., Woolley, A.W., Chabris, C., & Malone, T. (2012). The Effects of Cognitive Diversity on Collective Intelligence and Team Learning. Paper presented at the 12th Annual Trans-Atlantic Doctoral Conference, London Business School, London, England.

Aggarwal, I., Woolley, A.W., Chabris, C., & Malone, T. (2012). The Effects of Cognitive Diversity on Collective Intelligence and Team Learning. Symposium presentation at the 13th Meeting of the Society for Personality and Social Psychology, San Diego, CA.

Aggarwal, I., Woolley, A.W., Chabris, C., & Malone, T. (2011). The relationship between collective intelligence, cognitive diversity and team learning. Paper presented at the 71st Meeting of the Academy of Management, San Antonio, TX.

Chabris, C.F. (2011). A collective intelligence factor in the performance of human groups. Presented at the Toulouse School of Economics, Toulouse, France, September 2011.

Chabris, C.F. (2011). Three surprising facts about individual, heritable, human intelligence. Presented at the Yale University Psychology Department Cognition Seminar, October 2011.

Chabris, C.F. (2011). Collective Intelligence: What Is It, Why Does It Matter, and How Can We Increase It? Presented at the Annual Meeting of the New England Association of Schools and Colleges, Boston, MA, December 2011.

Chabris, C.F. (2012). Collective Intelligence and Individual Intelligence. Presented at the University of Illinois Psychology Department Seminar Series, Champaign, IL, February 2012.

Chabris, C.F. (2012). A collective intelligence factor in the performance of human groups. Presented at the Team-Based Learning Conference, Tampa, FL, March 2012.

Chabris, C.F. (2012). Aristotle’s Hypothesis and the Relationship Between Individual and Collective Intelligence. Presented at the Conference on Collective Intelligence, MIT, Cambridge, MA, April 2012.

Chabris, C.F. (2012). Aristotle’s Hypothesis and the Relationship Between Individual and Collective Intelligence. Presented at the RPI Cognitive Science Colloquium, Troy, NY, April 2012.

Chabris, C.F. (2012). Women and the collective intelligence of human groups. Presented at the National Conference on Women in Information Technology, Chicago, IL, May 2012.

Chabris, C.F. (2013). Aristotle’s hypothesis and the relationship between individual intelligence and collective intelligence. Presented at the Society for Personality and Social Psychology Judgment and Decision Making Preconference, New Orleans, 16 January.

Chabris, C.F. (2013). Aristotle's hypothesis about the nature of collective intelligence. Presented at the Union College Computer Science Department Seminar Series, January 2013.

Chabris, C.F. (2012). Thinking Together: The New Science of Collective Intelligence. Presented at the Neuroleadership Summit, New York, October 2012.

Malone, T. W. (2012). Collective Intelligence: What is it? How can we measure it? And how can we increase it? University of California – Irvine, Trends in Society and Information Technology Seminar Series, Irvine, CA, February 10, 2012.

Malone, T. W. (2012). Collective Intelligence: What is it? How can we measure it? And how can we improve it? Seminar in honor of Thomas W. Malone (including three other speakers), University of Zurich, Zurich, Switzerland, April 27, 2012.

Malone, T. W. (2012). Collective Intelligence: What is it? How can we measure it? And how can we increase it? Departmental Colloquium, Stanford University Psychology Department, Stanford, CA, May 30, 2012.

Malone, Thomas W., Collective Intelligence: What is it? How can we measure it? And how can we increase it? Union of Concerned Scientists, Cambridge, MA, March 7, 2013.

Malone, Thomas W., Collective Intelligence, Foresight Workshop, Atlantic Council of the United States, Washington, DC, April 23, 2013.

Malone, Thomas W., Big Data: Applying Collective Intelligence to Drive Business Outcomes, IBM THINK Finance: The CFO+CIO Leadership Exchange, New York, NY, May 22, 2013.

Malone, Thomas W., How can we create more intelligent organizations? MIT Club of Boston, Boston Seminar Series, Boston, MA, May 23, 2013.

Malone, Thomas W., How can we create more intelligent organizations? MIT Sloan School of Management Alumni Reunion Back to the Classroom event, Cambridge, MA, June 8, 2013.

Nagar, Y. (2012) Thinking together: Connecting People and Computers in Collective Intelligence Systems. Presented at the Department of Industrial Engineering, Ben-Gurion University, Beer-Sheva, Israel, Aug 2012.

Nagar, Y., & Malone, T. W. (Nov 2011). Making Business Predictions by Combining Human and Machine Intelligence in Prediction Markets. First Cambridge Area Economics and Computation Day (CAEC '11)

Nagar, Y. (Aug 2012) Thinking together: Connecting People and Computers in Collective Intelligence Systems. Presented at the Department of Industrial Engineering, Ben-Gurion University, Beer-Sheva, Israel.

Woolley, A. W. (2012). Collective Intelligence in Human Groups. Presented at the Conference on Collective Intelligence, MIT, Cambridge, MA, April 2012

Number of Presentations: 30.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
08/25/2011	6.00	Julia B Bear, Anita Williams Woolley. The Role of Gender in TeamCollaboration and Performance, INTERDISCIPLINARY SCIENCE REVIEWS, Vol. 36 No. 2, June, 2011, 146–53. 02-JUN-11, . : ,
12/03/2013	15.00	Yiftach Nagar, Thomas W. Malone. Improving Predictions with Hybrid Markets, AAAI Fall Symposium: Machine Aggregation of Human Judgment. 01-OCT-12, . : ,

TOTAL: **2**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
08/24/2011	2.00	Yiftach Nagar , Thomas W. Malone. Combining Human and Machine Intelligence for Making Predictions, Computational Social Science and the Wisdom of Crowds Workshop . 10-DEC-11, . : ,
08/24/2012	11.00	Yiftach Nager, Thomas Malone. Making Business Predictions by Combining Human and Machine Intelligence in Prediction Markets, Thirty Second International Conference on Information Systems. 05-DEC-11, . : ,
08/24/2012	10.00	Yiftach Nager. Beyond the Human-Computation Metaphor, Proceedings of The Third IEEE International Conference on Social Computing. 10-OCT-11, . : ,
08/24/2012	12.00	Yiftach Nager. What Do You Think: The Structuring of an Online Community as a Collective-Sensemaking Process, Proceedings of the 2012 ACM Conference on Computer Supported Collaborative Work. 15-FEB-12, . : ,
08/25/2011	3.00	Yiftach Nagar, Thomas W. Malone. Making Business Predictions by Combining Human and Machine Intelligence in Prediction Markets, ICIS 2011 Shanghai China. 12-JUL-11, . : ,
12/03/2013	14.00	Yiftach Nagar. Designing a collective-intelligence system for evaluating complex, crowd-generated intellectual artifacts, the 2013 conference. 23-FEB-13, San Antonio, Texas, USA. : ,

TOTAL: **6**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
08/25/2011	4.00	Yiftach Nagar,, Thomas W. Malone. Combining Human and Machine Intelligence for Making Predictions, Management Science (08 2011)
08/25/2011	5.00	Ishani Aggarwal , Anita Woolley , Christopher Chabris , Thomas W. Malone. The relationship between collective intelligence, cognitive diversity and team learning. , PNAS (08 2011)

TOTAL: **2**

Number of Manuscripts:

Books

Received	Paper
08/23/2012 8.00	Ishani Aggarwal, Anita Woolley. Two perspectives on intellectual capital and innovation in teams: Collective intelligence and Cognitive Diversity. In C. Mukhopadyay (Ed.), Driving the economy through innovation and entrepreneurship (pp. 495-502), United States: Springer, (11 2012)

TOTAL: 1

Patents Submitted

Patents Awarded

Awards

Our article on measuring collective intelligence, published in late 2010 in SCIENCE magazine, received extensive media coverage at the time of publication, with mentions in over 40 outlets including: NYTimes, ScienceDaily, Wall Street Journal, National Geographic, Discovery Channel, Boston Globe, COSMOS magazine (Australia), Globe and Mail (Canada), La Tercera (Chile), La Vanguardia (Spain), and The Telegraph (India).

This research continues to attract significant attention in both scholarly and other publications. For instance, according to Google Scholar, it has been cited over 130 times in approximately 2 years in scholarly publications, and we are aware of one recent introductory psychology textbook that includes a boxed summary of the work (Cacciopo & Freberg, 2013).

In addition, the Doonesbury comic strip on July 15, 2012, was based on the results of our research (see http://doonesbury.slate.com/strip/archive/2012/07/15). The comic strip includes one "error" in its summary of our research results. The Doonesbury character says that "Group IQ doesn't correlate with the average IQ of its members," but we actually found a "modest" correlation rather than no correlation. Otherwise, the results summarized in the comic strip correspond very closely to the actual results of our research as published in Science magazine.

Other honors include:

(a) Malone was Co-Organizer for first-ever Collective Intelligence conference held at MIT with over 200 attendees, April 2012. Chabris and Woolley were invited plenary speakers.

(b) Malone received a Honorary doctorate, University of Zurich, April 2012.

(c) Malone was interviewed for THE EDGE website on the topic of “Collective Intelligence” (video interview available online at: http://www.edge.org/conversation/collective-intelligence). Other recent interviews on this website include: Nobel prize-winner Daniel Kahneman, and other high-profile academics such as Jared Diamond, Daniel Dennett, Daron Acemoglu, and Nicholas Christakis. The interview was also summarized in a NEW YORK TIMES column by Andrew Revkin: http://dotearth.blogs.nytimes.com/2012/12/03/exploring-humanitys-evolving-global-brain/ .

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Nada Hashmi	0.00	
Ishani Aggarwal	0.00	
Yiftach Nagar	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
David Engel	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Anita Woolley	0.00	
Thomas Malone	0.00	
Christopher Chabris	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**3**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Eric Emer	0.00	
Olivia Basil	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**2**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME
Ishani Aggarwal

Total Number: **1**

Names of other research staff

NAME	PERCENT_SUPPORTED
Lisa Jing	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

During the course of this project, we have developed and refined a battery to test group performance on a wide variety of tasks. Our studies revealed that there is a single statistical factor that explains more than 40% of the variance in a group's performance on all these tasks. These results provide converging evidence that there exists a general collective intelligence factor for groups that is analogous to previous measures of intelligence at the individual level.

In this report we report several studies in a diverse set of contexts:

(1) The original study that was published in Science that demonstrated for the first time that for groups (just as for individuals) there is an underlying factor that explains a group's performance on a wide variety of tasks.

(2) Development and testing of an online version of the collective intelligence (CI) test battery which allows us to test face-to-face as well as on-line groups in under one hour. This study addresses the question: Can an online battery of tasks where a group collaborates through the Internet, using only text chat and shared editing tools, be used to efficiently capture CI?

(3) A study of the effect of social and individual interventions on CI: Which individual factors and social interactions are correlated to high CI?

(4) A study of the predictive power of CI for real world performance: Does CI predict how well a group will perform on complex tasks over time in military and academic settings?

(5) A study of the effect of CI on group learning: Are more collectively intelligent groups able to learn and improve their performance more rapidly?

(6) A study of the perception of CI by lay observers: Is CI a quality that lay observers can accurately judge after brief observation of the group working together?

In the following sections, we describe these research studies in greater detail.

INTRODUCTION

As research, management, and many other kinds of tasks are increasingly accomplished by groups rather than by individuals, it is becoming even more important to understand the determinants of group performance. Over the last century, psychologists made significant progress in defining and systematically measuring intelligence in individuals. But no one has used the statistical approach developed by psychologists for measuring individual intelligence to systematically measure the intelligence of groups. Even though social psychologists and others have studied for decades how well groups perform specific tasks, they have not attempted to measure group intelligence in the same way individual intelligence is measured—by assessing how well a single group can perform a wide range of different tasks, and using that information to predict how that same group will perform other tasks in the future. The goal of the research reported here was to test the hypothesis that groups, like individuals, have characteristic levels of "intelligence," which can be measured and used to predict the groups' performance on a wide variety of tasks.

Although controversy has surrounded it, the concept of measurable human intelligence is based on a fact that is still as remarkable as it was to Spearman when he first documented it in 1904: People who do well on one mental task tend to do well on most others, despite large variations in the tests' contents and methods of administration. In principle, performance on cognitive tasks could be largely uncorrelated, as one might expect if each relied on a specific set of capacities that was not used by other tasks. It could even be negatively correlated, if practicing to improve one task caused neglect of others. The empirical fact of general cognitive ability as first demonstrated by Spearman is now, arguably, the most replicated result in all of psychology.

In empirical terms, evidence of general intelligence is provided by the observation that the average correlation among individuals' performance scores on a relatively diverse set of cognitive tasks is positive, the first factor extracted in a factor analysis of these scores generally accounts for 30-50% of the variance, and subsequent factors extracted account for substantially less variance. This first factor extracted in an analysis of individual intelligence tests is referred to as "general cognitive ability," or "g," and it is the main factor that intelligence tests measure. What makes intelligence tests of substantial practical (not just theoretical) importance is that intelligence can be measured in an hour or less, and is a reliable predictor of a very wide range of important life outcomes over a long span of time, including grades in school, success in many occupations, and even life expectancy.

By analogy with individual intelligence, we define a group's collective intelligence (CI) as the general ability of the group to perform a wide variety of tasks. Empirically, collective intelligence is the inference one draws when the ability of a group to perform one task is correlated with that group's ability to perform a wide range of other tasks. Note that this kind of collective intelligence is a property of the group itself, not just the individuals in it. Unlike previous work that examined the effect on group performance of the average intelligence of individual group members, one of our goals is to determine whether the collective

intelligence of the group as a whole has predictive power above and beyond what can be explained by knowing the abilities of the individual group members.

(1) EVIDENCE FOR A COLLECTIVE INTELLIGENCE FACTOR IN GROUPS

The first question we examined was whether collective intelligence--in this sense--even exists. Is there a single factor for groups, a CI factor, that functions in the same way for groups as general intelligence does for individuals? Or does group performance, instead, have some other correlational structure, such as several equally-important but independent factors?

To answer this question, we invited individuals to our laboratories, randomly assigned them to groups, and asked them to perform a variety of different tasks together. In Study 1, 40 three-person groups worked together for up to 5 hours on a diverse set of 5 tasks plus a more complex criterion task. To guide our task sampling, we drew tasks from all quadrants of the McGrath Task Circumplex, a well-established taxonomy of group tasks based on the coordination processes they require. Tasks included solving visual puzzles, brainstorming, making collective moral judgments, and negotiating limited resources. At the beginning of each session, we measured team members' individual intelligence. And, as a criterion task at the end of each session, each group played checkers against a standardized computer opponent.

The results strongly support the hypothesis that a general collective intelligence factor (CI) exists in groups. First, average inter-item correlation for scores on different tasks is positive ($r=.28$, $p<.05$). Next, factor analysis of team scores yielded one factor with an initial eigenvalue accounting for over 43% of the variance (in the middle of the 30-50% range typical in individual intelligence tests), while the next factor accounts for only 18%. Furthermore, when the factor loadings for different tasks on the first general factor are used to calculate a CI score for each group, this score is highly predictive of performance on the criterion task ($r=.52$, $p=.01$). Finally, the average intelligence of group members is not significantly correlated with CI ($r=.19$, ns) and not predictive of criterion task performance ($r=.18$, ns).

In Study 2, we attempted to replicate these findings in groups of different sizes, using a broader sample of tasks and an alternative measure of individual intelligence. We also began to explore what characteristics of groups might predict their collective intelligence. We first examined the relationship among the same set of tasks used in Study 1, but this time with 153 groups ranging from two to five members. As expected, this study replicated the findings of Study 1, yielding a first factor explaining 44% of the variance and a second factor explaining only 20%.

Three factors were significantly correlated with CI. First, there was a significant correlation between CI and the average social sensitivity of group members, as measured by the "Reading the Mind in the Eyes" test; $r=.26$, $p=.002$. Second, CI was negatively correlated with the variance in the number of speaking turns by group members, as measured by the sociometric badge technology developed by Pentland and colleagues; $r= -.41$, $p=.01$. In other words, groups where a few people dominated the conversation were, in general, less collectively intelligent than those with a more equal distribution of conversational turn-taking. Finally, perhaps surprisingly, CI was positively and significantly correlated with the proportion of females in the group ($r=.23$, $p=.007$). However, this result appears to be largely mediated by social sensitivity (Sobel $z=1.93$, $p=.03$), since (consistent with previous research) women in our sample scored better on the social sensitivity measure than men.

In summary, these results provide substantial evidence for the existence of CI in groups, analogous to a well-known similar ability in individuals. Importantly, this collective intelligence factor appears to depend upon both the composition of the group (e.g., average member intelligence) and also on factors that emerge from the way group members interact when they are assembled (e.g., their conversational turn-taking behavior).

(2) DEVLOPING AND CROSS-VALIDATING AN ONLINE BATTERY TOOL FOR CAPTURING CI

In developing the online battery, our goal was to streamline a four-hour laboratory experiment into an efficient online tool that could be used by groups in under an hour. The tool allows us to study groups that work in different settings, from in-person groups that sit around a table to groups that collaborate purely over the internet. The tool has made our own research more efficient and collaboration in academic and industry settings more feasible. Additionally, it has allowed us to investigate questions about the role of technology in shaping group collaboration.

Our online battery consists of seven task groups that represent unique types of group ability. A group logs in to the tool at a scheduled time and the tool guides the group through the timed study automatically. Group members are able to communicate using a chat screen and a synchronized typing pad where each member's typing is displayed instantaneously to all members in the group.

For all the possibilities that the tool opens, it also raises questions about the comparability of the CI measurement captured by it and the measurement captured in the original laboratory setting where group members work together face-to-face.

We set out to cross-validate these results in a study that compared the performance of face-to-face groups and online groups.

We collected data from over 70 groups divided between these two conditions. Face-to-face groups worked together in a conference room, and each person had access to the online battery via an individual laptop computer. Online groups worked together on the online battery, but they could only communicate via text chat and the shared tasks in the battery.

Our results showed that just as in the original 4 hour, face-to-face study, the performances on all tasks are positively correlated with each other and that exactly as before (and in analogy to individual intelligence) one single factor emerges that explains more than 40% of the variance in the dataset while the next factors explain only 15% or less. Interestingly, we also found that the inter-task correlations as well as the factor structure are almost identical for face-to-face and online groups.

(3) FACTORS INFLUENCING CI

The next important question is: What factors drive collective intelligence in groups? Aggregating over several studies in several different contexts and with different variations of our battery we now know at least five factors that are correlated with CI: Amount of Communication, Distribution of Communication, Distribution of Work, Percentage Women and Theory of Mind abilities.

a) Amount of communication: In the original study as well as in the face-to-face and chat-only versions of the new online battery, amount of communication was always significantly and positively correlated with CI. This means that the more groups interact with each other the higher their performance on group tasks. In the chat-only cases this was measured by analyzing the chat transcripts, whereas in the face-to-face scenarios we measured the amount of spoken communication.

b) Distribution of communication: Analyzing the same data as above but this time for distribution, we found that groups where each member contributes equally to the interaction perform better than groups in which the communication is dominate by one or two group members.

c) Distribution of work: Our online tool allows us to record and analyze who contributed which answer to which question and we find that again that the more equal the group members' contributions are, the higher the CI of the group.
d) Percentage of women: Surprisingly, the percentage of women in a group is significantly and positively correlated with general group performance as measured by CI. This correlation seems to be mediated by higher social perceptiveness skills of women (see e))

e) Theory of Mind: The ability to reason about other people's mental states is called "theory of mind." One of the most common tests of theory of mind in non-clinical population is the Reading the Mind in the Eyes Test (RME) which asks participants to determine complex emotional states of people from just observing their eye regions. We found that RME is significantly correlated with CI in all major studies that we've run so far. Most interestingly, the correlation between CI and RME is almost identical in both face-to-face and online groups, even though online groups never saw each other's eyes and had severely reduced communication bandwidth. This led us to the conclusion that broader theory of mind skills-- not just facial perception or non-verbal communication skills--are the driving factor behind this correlation.

(4) PREDICTIVE OR CORRELATIVE SIGNIFICANCE OF CI FOR REAL WORLD PERFORMANCE

Is collective intelligence predictive of how a real world group will do in academic, industry or military contexts? We are beginning to answer this question by administering our battery at field sites including the Army Fires Center of Excellence in Fort Sill, Oklahoma, Carnegie Mellon University Tepper School of Business, University of Erlangen-Nuremberg, Germany and the Fuji Xerox Corporation in Japan.

At Fort Sill and Carnegie Mellon, we are investigating whether our battery can predict group performance in these respective field settings. At Fort Sill, we tested groups of 3 to 6 Army officers enrolled in a Basic and Advanced Officer Leadership Training Course at the start of their course. We intend to compare how a pre-course measure of collective intelligence correlates with the instructors' post-course evaluations of these groups. Up through late 2011, we administered the battery to 40 groups and collected course performance data for half of them. Unfortunately, the testing has been stalled due to scheduling conflicts at Fort Sill. If possible, we would like to resume testing and are seeking contacts to help.

At Carnegie Mellon, we administered our battery to 50 groups of MBA students enrolled in a course on Managing Organizations. As prospective leaders in business, these students work in teams throughout the semester on a number of projects, including a capstone project in which they develop a case study of a significant issue facing a senior leader We find that teams' CI scores significantly predict their performance on a number of decision-making exercises in the course, as well as performance on their final project.

At the University of Erlangen-Nuremberg, we administered our battery to 114 groups of students tasked with designing solutions to social problems which incorporate tablet technology. We are exploring how collective intelligence, and the other individual and group characteristics that we capture in our battery, correlate with innovation. In our analysis so far, we have found that the correlations between the CI factor and their project evaluations are significant. In fact, the strongest correlation that we found

was between CI and the metric indicating how innovative the projects were.

At Fuji-Xerox, we are exploring whether our battery is culturally and linguistically translatable by testing it in a Japanese corporate setting. Our battery has been translated entirely into Japanese. We have adapted some verbally intensive tasks into their Japanese analogues and have substituted others with non-verbal versions. We are about to test 25 groups of 4 subjects each and are hoping to establish the comparability of American and Japanese groups' performance on a battery. In addition, we are interested in whether the factors influencing collective intelligence are similar across cultures. Eventually, we also hope to discover how the battery can have relevant corporate application by using it to observe the group processes that underlie collectively intelligent work teams.

(5) EFFECT OF SOCIAL AND INDIVIDUAL INTERVENTIONS ON CI

We are also undertaking three studies on whether interventions into group or individual behavior will impact collective intelligence and, in some cases, as an indicator for the efficacy of these interventions.

The first is a cross-cultural study done in collaboration with the Rebecca Saxe Lab at MIT. We are comparing the group performance of culturally homogenous and culturally heterogeneous groups whose members are from nations in conflict. In addition, we hope to test groups of American and Arab youth who have participated in a program to decrease mutual prejudice. Initially, we will measure the collective intelligence of random groups of participants at the program's start. We will take another measurement of reshuffled groups at the program's end. In this study we are not interested in the change in CI in intact groups, but rather, the effect of an individual behavioral and perceptual intervention on members' ability to develop CI in groups. For this study to be possible, we have focused on developing a culturally neutral battery with non verbally-intensive tasks so as not to bias it towards native English speakers.

The second study is being done at Carnegie Mellon University on the effects of a prior cooperative or competitive group interaction on the emergence of collective intelligence in the group. Three-person groups complete a decision-making task in which the cooperative or competitive motivations of team members are experimentally manipulated. Then, we administer the battery to observe whether the effects of this manipulation carry over to the collective intelligence of these groups. The hypothesis is that groups encouraged to engage in cooperative group interaction will develop higher collective intelligence than competitive groups. At this point, we have collected data from 60 groups and are in the process of collecting more.

The third study is in collaboration with the Team-Based Learning Collaborative and Skidmore College. Team-based learning is a curricular method that guides groups of students to learn together. It has been shown that this method enhances the learning of individuals in comparison with traditional isolated forms of learning. We will administer the battery to teams at the beginning and at the end of courses that incorporate team-based learning. We are interested in how the team-based learning method will impact collective intelligence overtime. For example, if the general trend is that CI increases, do members of teams which were initially more collectively intelligent benefit more from team-based learning and improve more rapidly than members of initially less collectively intelligent teams?

(6) THE EFFECT OF COLLECTIVE INTELLIGENCE ON LEARNING

Using data collected from the studies in our Science paper, we are currently writing a paper on the impact of collective intelligence on group learning. We found that groups with a higher collective intelligence also learn more rapidly as indicated by their performances on a tacit coordination game. This game is modeled after the prisoner's dilemma, except that groups are rewarded for coordinating their private individual choices to be as similar, and in this case, mutually beneficial, as possible without speaking. They play the game for ten rounds in order to capture how well the group can learn to coordinate and to succeed together. In a second study, we measure the collective intelligence of 60 MBA student teams and then observe their performance on group-based exams over the course of a semester together. We find that collective intelligence significantly predicts the performance of groups on the exams as well as their rate of improvement over the course of three exams. Furthermore, highly collectively intelligent groups consistently performed better than their best member on the exams, while less collectively intelligent groups did not.

(7) PERCEIVING COLLECTIVE INTELLIGENCE BY LAY OBSERVERS

Also using data collected from the studies in our original Science paper, we are exploring the perception of collective intelligence by lay observers. Can lay observers predict how collectively intelligent a group is by watching a ninety-second video clip of the group working together on our CI battery? Our preliminary results (based on studies of approximately 80 observers) suggest that collective intelligence is perceptible by observers but that their accuracy varies according to the size of the groups being observed, with smaller groups being easier to judge accurately. We are continuing to collect data to test the limits of this observation: how long do observers need to watch? Is collective intelligence more readily observable for some kinds of tasks than others?

SUMMARY

In this project, we have focused on developing and applying tests for measuring collective intelligence in a variety of academic and industry contexts. Our findings have led us to develop a more mature understanding of the qualities of collective intelligence, including: how it can be improved, how it affects learning, how it is perceived by observers, how group competitiveness affects it, and how technology enhances it.

Technology Transfer